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Mr. Iſaac Newtons *Anſwer to ſome Conſiderations upon his Doctrine of* Light *and* Colors; *which Doctrine was printed in* Numb. 80. *of theſe Tracts.*

SIR, I have already told you, that at the peruſal of the Conſiderations, you ſent me, on my Letter concerning *Refractions* and *Colors*, I found nothing, that, as I conceived, might not without difficulty be anſwer'd. And though I find the *Conſiderer* ſomewhat more concern'd for an *Hypotheſis*, than I expected; yet I doubt not, but we have one common deſign; I mean, a ſincere endeavour after knowledge, without valuing uncertain ſpeculations for their ſubtleties, or deſpiſing certainties for their plainneſs: And on confidence of this it is, that I make this return to his diſcourſe.*

1. *Of the Practique part of Optiques.*

The *firſt* thing that offers it ſelf is leſs agreeable to me, and I begin with it becauſe it is ſo. The conſiderer is pleaſed to reprehend me for laying aſide the thoughts of improving Optiques by *Refractions.* If he had obliged me by a private Letter on this occaſion, I would have acquainted him with my ſucceſſes on the Tryals I have made of that kind, which I ſhall now ſay have been leſs than I ſometimes expected, and perhaps than he at preſent hopes for. But ſince he is pleaſed to take it for granted, that I have let this ſubject paſs without due examination, I ſhall refer him to my former Letter, * by which that conjecture will appear to be un-grounded. For, what I ſaid there, was in reſpect of Teleſcopes of the ordinary conſtruction, ſignifying, that their improvement is not to be expected from the *well-figuring* of Glaſſes, as Opticians have imagin'd; but I deſpaired not of their improvement by other conſtructions; which made me cautious to inſert nothing that might intimate the contrary. For, although ſucceſſive refractions that are all made the ſame way, do neceſſarily more and more augment the errors of the firſt refraction; yet it ſeem'd not impoſſible for *contrary* refractions ſo to correct each others inequalities, as to make their difference regular; and, if that could be conveniently effected, there would be no further difficulty. Now to this end I examin'd, what may be done not only by *Glaſſes alone*, but more eſpecially by a Complication of divers ſucceſſive *Mediums*, as by two or more Glaſſes or Cryſtals with Water or ſome other fluid between them; all which together may perform the office of *one Glaſs*, eſpecially of the Object-glaſs, on whoſe conſtruction the perfection of the inſtrument chiefly depends. But what the reſults in Theory or by Tryals have been, I may poſſibly find a more proper occaſion to declare.

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* *Which* Diſcourſe *was thought needleſs to be here printed at length, becauſe in the body of this Anſwer are to be met with the chief particulars, wherein the* Anſwerer *was concern'd.*

* *Printed in* Numb. 80. *of theſe Tracts.*

To the Aſſertion, that Rays are leſs true *reflected* to a point by a *Concave*, than *refracted* by a Convex, I cannot aſſent; nor do I underſtand, that the *focus* of the latter is leſs a line than that of the former. The truth of the contrary you will rather perceive by this following Table, computed for ſuch a *Reflecting Concave*, and *Refracting convex*, on ſuppoſition that they have equal Apertures, and collect parallel rays at an equal diſtance from their *vertex*; which diſtance being divided into 15000 parts, the Diameter of the Concave Sphere will be 60000 of thoſe parts, and of the Convex, 10000; ſuppoſing the *Sines* of Incidence and Refraction to be, in round numbers, as 2 to 3. And this Table ſhews, how much the exterior rays, at ſeveral Apertures, fall ſhort of their principal *focus*.

The Diameter of the Aperture.	*The parts of the Axis intercepted between the* vertex *and the rays.*		*The Error by*	
	Reflected.	*Refracted.*	*Reflexion*	*Refraction.*
2000	$14991\frac{2}{3}$	14865	$8\frac{1}{3}$	135 .
4000	14966	14449	33	551 .
6000	14924	13699	76	1301 :
8000	14865	12475	135	2525 :
10000	14787	9472	213	5528 .

By this you may perceive, that the Errors of the *Refracting convex* are ſo far from being *leſs*, that they are more than ſixteen times greater than the like errors of the *Reflecting Concave*, eſpecially in great Apertures; and that without reſpect to the Heterogeneous conſtitution of light. So that, however the contrary ſuppoſition might make the Author of theſe Animadverſions reject *Reflections* as uſeleſs for the promoting of Op-

tiques

tiques; yet I muſt for this as well as other conſiderations prefer them in the Theory before *Refractions*.

Whether the *Parabola* be more difficult to deſcribe than the *Hyperbola* or *Ellipſis*, may be a *Quære*: But I ſee no abſolute neceſſity of endeavouring after any of their deſcriptions. For, if Metals can be ground truly Spherical, they will bear as great Apertures, as I believe men will be well able to communicate an *exact* poliſh to. And for Dioptrique Teleſcopes, I told you, that the difficulty conſiſted not in the Figure of the glaſs, but in the Difformity of Refractions: Which if it did not, I could tell you a better and more eaſie remedy than the uſe of the *Conic Sections*.

2. Of the Theorique part.

Thus much concerning the *Practique* part of Optiques. I ſhall now take a view of the Conſiderations on my *Theories*. And thoſe conſiſt in aſcribing an *Hypotheſis* to me, which is not mine; in Aſſerting an *Hypotheſis*, which, as to the principal parts, is not againſt me; in Granting the greateſt part of my diſcourſe if explicated by that *Hypotheſis*; and in Denying ſome things, the truth of which would have appear'd by an experimental examination.

3. Of an Hypotheſis miſtaken to be mine.

Of theſe Particulars I ſhall diſcourſe in order. And firſt of the *Hypotheſis*, which is aſcribed to me in theſe words: *But grant his firſt ſuppoſition, that light is a body, and that as many colours or degrees as there may be, ſo many bodies there may be; all which compounded together would make White*, &c. This, it ſeems, is taken for my *Hypotheſis*. 'Tis true, that from my Theory I argue the *Corporeity* of Light; but I do it without any abſolute poſitiveneſs, as the word *perhaps* intimates; and make it at moſt but a very plauſible *conſequence* of the Doctrine, and not a fundamental *Suppoſition*, nor ſo much as any part of it; which was wholly comprehended in the precedent Propoſitions. And I ſomewhat wonder, how the *Objector* could imagine, that, when I had aſſerted the Theory with the greateſt rigour, I ſhould be ſo forgetful as afterwards to aſſert the fundamental ſuppoſition it ſelf with no more than a *perhaps*. Had I intended any ſuch *Hypotheſis*, I ſhould ſomewhere have explain'd it. But I knew, that the *Properties*, which I declar'd of *Light*, were in ſome meaſure capable of being explicated not only by that, but by many other Mechanical *Hypotheſes*. And therefore I choſe to decline them all, and to ſpeak of *Light* in *general* terms, conſidering it abſtractly, as ſomething or other propagated every way in ſtreight lines from luminous bodies, without determining, what that Thing is; whether a confuſed Mixture of difform qualities, or Modes of bodies, or of Bodies themſelves, or of any Virtues, Powers, or Beings whatſoever. And for the ſame reaſon I choſe to ſpeak of *Colours* according to the information of our Senſes, as if they were Qualities of Light *without* us. Whereas by that *Hypotheſis* I muſt have conſidered them rather as *Modes* of Senſation, excited in the mind by various motions, figures, or ſizes of the corpuſcles of Light, making various Mechanical impreſſions on the Organ of Senſe; as I expreſſed it in that place, where I ſpake of the Corporeity of Light.

But ſuppoſing I had propounded that *Hypotheſis*, I underſtand not, why the Objector ſhould ſo much endeavour to oppoſe it. For certainly it has a much greater affinity with his own *Hypotheſis*, than he ſeems to be aware of; the Vibrations of the *Æther* being as uſeful and neceſſary in *this*, as in *his*. For, aſſuming the Rays of Light to be ſmall bodies, emitted every way from Shining ſubſtances, thoſe, when they impinge on any Refracting or Reflecting ſuperficies, muſt as neceſſarily excite Vibrations in the *æther*, as Stones do in water when thrown into it. And ſuppoſing theſe Vibrations to be of ſeveral depths or thickneſſes, accordingly as they are excited by the ſaid corpuſcular rays of various ſizes and velocities; of what uſe they will be for explicating the manner of Reflection and Refraction, the production of Heat by the Sun-beams, the Emiſſion of Light from burning putrifying, or other ſubſtances, whoſe parts are vehemently agitated, the *Phænomena* of thin tranſparent Plates and Bubles, and of all Natural bodies, the Manner of Viſion, and the Difference of Colors, as alſo their Harmony and Diſcord; *I* ſhall leave to their conſideration, who may think it worth their endeavor to apply this *Hypotheſis* to the ſolution of *phænomena*.

4. Of the objector's Hypotheſis, *and that the moſt free and genuine Conſtitution of that and all other Mechanical Hypotheſes is conformable to my Doctrine.*

In the ſecond place, I told you, that the Objectors *Hypotheſis*, as to the fundamental part of it, is not againſt me. That fundamental Suppoſition is; *That the parts of bodies, when briskly agitated, do excite Vibrations in the Æther, which are propagated every way from thoſe bodies in ſtreight lines, and cauſe a Senſation of Light by beating and daſhing againſt the bottom of the Eye, ſomething after the manner that Vibrations in the Air cauſe a Senſation of Sound by beating againſt the Organs of Hearing.* Now, the moſt free and natural Application of this *Hypotheſis* to the Solution of *phænomena* I take to be this: *That* the agitated parts of bodies, according to their ſeveral ſizes, figures, and motions, do excite Vibrations in the *æther* of various depths or bigneſſes, which being promiſcuouſly propagated through that *Medium* to our Eyes, effect in us a Senſation of Light of a *White* colour; but if by any means thoſe of unequal bigneſſes be ſeparated from one another, the largeſt beget a Senſation of a *Red* colour, the leaſt or ſhorteſt, of a deep *Violet*, and the intermediat ones, of intermediat colors; much after the manner that bodies, according to their ſeveral ſizes, ſhapes, and motions, excite vibrations in the Air of various bigneſſes, which, according to thoſe bigneſſes, make ſeveral Tones in Sound: *That* the largeſt Vibrations are beſt able to overcome the reſiſtance of a Refracting ſuperficies, and ſo break through it with leaſt Refraction; whence the Vibrations of ſeveral bigneſſes, that is, the Rays of ſeveral Colors, which are blended together in Light, muſt be parted from one another by Refraction, and ſo cauſe the *Phænomena* of *Priſmes* and other refracting ſubſtances: And *that* it depends on the thickneſs of a thin tranſparent Plate or Buble, whether a Vibration ſhall be *reflected* at its further ſuperficies, or *tranſmitted*; ſo that, according to the number of vibrations, interceding the two ſuperficies, they may be reflected or tranſmitted for many ſucceſſive thickneſſes. And ſince the Vibrations which make *Blew* and *Violet*, are ſuppoſed ſhorter than thoſe which make *Red* and *Yellow*, they muſt be reflected at a leſs thickneſs of the Plate: Which is ſufficient to explicate all the ordinary *phænomena* of thoſe Plates or Bubles, and alſo of all natural bodies, whoſe parts are like ſo many fragments of ſuch Plates.

Theſe ſeem to be the moſt plain, genuine and neceſſary conditions of this *Hypotheſis*: And they agree ſo juſtly with my Theory, that if the *Animadverſor* think fit to apply them, he need not, on that account, apprehend a divorce from it. But yet how he will defend it from other difficulties, I know not. For, to me, the Fundamental Suppoſition it ſelf ſeems impoſſible; namely, That the *Waves* or Vibrations of any Fluid, can, like the Rays of Light, be propagated in *Streight* lines, without a continual and very extravagant ſpreading and bending every way into the quieſcent Medium, where they are terminated by it. I miſtake, if there be not both Experiment and Demonſtration to the contrary. And as to the other two or three *Hypotheſes*, which he mentions, I had rather believe them ſubject to the like difficulties, than ſuſpect the *Animadverſor* ſhould ſelect the worſt for his own.

What I have ſaid of this, may be eaſily applied to all other *Mechanical Hypotheſes*, in which Light is ſuppoſed to be cauſed by any Preſſion or Motion whatſoever, excited in the *æther* by the agitated parts of Luminous bodies. For, it ſeems impoſſible, that any of thoſe Motions or Preſſions can be propagated in *Streight* lines without the like ſpreading every way into the ſhadow'd Medium, on which they border. But yet, if any man can think it poſſible, he muſt at leaſt allow, that thoſe Motions or Endeavors to motion, cauſed in the *æther* by the ſeveral parts of any Lucid body that differ in ſize, figure, and agitation, muſt neceſſarily be unequal: Which is enough to denominate Light an Aggregat of *difform* rays, according to any of thoſe Hypotheſes. And if thoſe Original inequalities may ſuffice to difference the Rays in Colour and Refrangibility, I ſee no reaſon, why they, that adhere to any of thoſe *hypotheſes*, ſhould ſeek for other Cauſes of theſe Effects, unleſs (to uſe the *Objectors* argument) they will multiply entities without neceſſity.

The *third* thing to be conſidered is, the Condition of the *Animadverſor's* Conceſſions, which is, that I would explicate my *Theories* by his *Hypotheſis*: And if I could comply with him in that point,

5. *Of the* Animadverſor's *Conceſſions, and their limitation to his Hypotheſis.*

there would be little or no difference between Us. For he grants, that without any reſpect to a different Incidence of rays there are different Refractions; but he would have it explicated, not by the different Refrangibility of ſeveral Rays, but by the Splitting and Rarefying of æthereal pulſes. He grants my *third*, *fourth* and *ſixth* Propoſitions; the ſenſe of which is, That Un-compounded Colors are unchangeable, and that Compounded ones are changeable only by reſolving them into the colors, of which they are compounded; and that all the Changes, which can be wrought in Colours, are effected only by variouſly mixing or parting them: But he grants them on condition that I will explicate Colors by the two ſides of a ſplit pulſe, and ſo make but two *ſpecies* of them, accounting all other Colors in the world to be but various degrees and dilutings of thoſe two. And he further grants, that *Whiteneſſe* is produced by the Convention of all Colors; but then I muſt allow it to be not only by Mixture of thoſe Colors, but by a farther Uniting of the parts of the Ray ſuppoſed to be formerly ſplit.

If I would proceed to examine theſe his Explications, I think it would be no difficult matter to ſhew, that they are not only *inſufficient*, but in ſome reſpects to me (at leaſt) *un-intelligible*. For, though it be eaſie to conceive, how Motion may be dilated and ſpread, or how parallel motions may become diverging; yet I underſtand not, by what artifice any *Linear* motion can by a refracting ſuperficies be *infinitely* dilated and rarefied, ſo as to become *Superficial*: Or, if that be ſuppoſed, yet I underſtand as little, why it ſhould be ſplit at ſo ſmall an angle only, and not rather ſpread and diſperſed through the whole angle of Refraction. And further, though I can eaſily imagine, how Unlike motions may croſs one another; yet I cannot well conceive, how they ſhould coaleſce into one *uniform* motion, and then part again, and recover their former Unlikeneſs; notwithſtanding that I conjecture the ways, by which the *Animadverſor* may endeavour to explain it. So that the Direct, uniform and undiſturbed Pulſes ſhould be ſplit and diſturbed by Refraction; and yet the Oblique and diſturbed Pulſes perſiſt without ſplitting or further diſturbance by following Refractions, is (to me) as unintelligible. And there is as great a difficulty in the Number of Colours; as you will ſee hereafter.

6. That it is not neceſſary, to limit or explain my Doctrine by any Hypotheſis.

But whatever be the advantages or diſadvantages of this *Hypotheſis*, I hope I may be excuſed from taking it up, ſince I do not think it needful to explicate my Doctrine by any *Hypotheſis* at all. For if *Light* be conſider'd abſtractedly without reſpect to any *Hypotheſis*, I can *as* eaſily conceive, that the ſeveral parts of a ſhining body may emit rays of differing colours and other qualities, of all which Light is conſtituted, *as* that the ſeveral parts of a falſe or uneven ſtring, or of uneavenly agitated water in a Brook or Cataract, or the ſeveral Pipes of an Organ inſpired all at once, or all the variety of Sounding bodies in the world together, ſhould produce ſounds of ſeveral Tones, and propagate them through the Air confuſedly intermixt. And, if there were any natural bodies that could *reflect* ſounds of one tone, and ſtifle or *tranſmit* thoſe of another; then, as the *Echo* of a confuſed Aggregat of all Tones would be that particular Tone, which the Echoing body is diſpoſed to reflect; ſo, ſince (even by the *Animadverſor's* conceſſions) there are bodies apt to *reflect* rays of one colour, and ſtifle or *tranſmit* thoſe of another; I can as eaſily conceive, that thoſe bodies, when illuminated by a mixture of all colours, muſt appear of that colour only which they reflect.

But when the *Objector* would inſinuate a difficulty in theſe things, by alluding to Sounds in the ſtring of a *M*uſical inſtrument before percuſſion, or in the Air of an Organ Bellowes before its arrival at the Pipes; I muſt confeſs, I underſtand it as little, as if one had ſpoken of Light in a piece of Wood before it be ſet on fire, or in the oyl of a Lamp before it aſcend up the match to feed the flame.

7. The difficulties of the Animadverſors *diſcourſe abſtracted from* Hypotheſes, *and conſider'd more generally.*

You ſee therefore, how much it is beſides the buſineſs in hand, to diſpute about *Hypotheſes*. For which reaſon I ſhall now in the laſt place, proceed to abſtract the difficulties in the *Animadverſor's* diſcourſe, and, without having regard to any *Hypotheſis*, conſider them in general terms. And they may be reduced to theſe 3 *Queres*:

1. Whether the unequal Refractions, made without reſpect to any inequality of incidence, be cauſed by the different Refrangibility of ſeveral Rays; or by the ſplitting, breaking or diſſipating the ſame Ray into diverging parts?

2. Whether there be more than two ſorts of Colours?

3. Whether Whiteneſs be a mixture of all Colours?

3. *That the Ray is not ſplit, or any otherwiſe dilated.*

The *Firſt* of theſe *Quæres* you may find already determin'd by an Experiment in my former Letter; the deſign of which was to ſhew, That the length of the colour'd Image proceeded not from any unevenneſs in the Glaſs, or any other *contingent* Irregularity in the Refractions. Amongſt other Irregularities I know not, what is more obvious to ſuſpect, than a fortuitous dilating and ſpreading of Light after ſome ſuch manner, as *Des-Cartes* hath deſcribed in his Æthereal Refractions for explicating the *Tayle* of a *Comet*; or as the *Animadverſor* now ſuppoſes to be effected by the Splitting and Rarifying of his Æthereal Pulſes. And to prevent the ſuſpicion of any ſuch Irregularities, I told you, that I refracted the Light contrary ways with two Priſmes ſucceſſively, to deſtroy thereby the *Regular* effects of the *firſt* Priſme by the *ſecond*, and to diſcover the *Irregular* effects by augmenting them with iterated refractions. Now, amongſt other Irregularities, if the *firſt* Priſme had ſpread and diſſipated every ray into an indefinit number of diverging parts, the *ſecond* ſhould in like manner have ſpread and diſſipated every one of thoſe parts into a further indefinite number, whereby the Image would have been ſtill more dilated, contrary to the event. And this ought to have hapned, becauſe thoſe Linear diverging parts depend not on one another for the manner of their Refraction, but are every one of them as truly and compleatly Rays as the whole was before its Incidence; as may appear by intercepting them ſeverally.

The reaſonableneſs of this proceeding will perhaps better appear by acquainting you with this further circumſtance. I ſometimes placed the *ſecond* Priſme in a poſition Tranſverſe to the *firſt*, on deſign to try, if it would make the long Image become four-ſquare by refractions croſſing thoſe that had drawn the round Image into a long one. For, if amongſt other Irregularities the Refraction of the *firſt* Priſme, did by Splitting dilate a Linear ray into a Superficial, the Croſs refractions of that *ſecond* Priſme ought by further ſplitting to dilate and draw that Superficial ray into a Pyramidal ſolid. But, upon tryal, I found it otherwiſe; the Image being as regularly Oblong as before, and inclin'd to both the Priſmes at an angle of 45. degrees.

I tryed alſo all other Poſitions of the ſecond Priſme, by turning the Ends about its middle part; and in no caſe could obſerve any ſuch Irregularity. The Image was ever alike inclined to both Priſmes, its Breadth anſwering to the Suns Diameter, and its length being greater or leſs accordingly as the Refractions more or leſs agreed, or contradicted one another.

And by theſe Obſervations, ſince the Breadth of the Image was not augmented by the Croſs refraction of the *ſecond* Priſme, that refraction muſt have been perform'd *without* any ſplitting or dilating of the ray; and therefore at leaſt the Light incident on that Priſme muſt be granted an Aggregat of Rays *unequally refrangible* in my ſenſe. And ſince the Image was equally inclin'd to both *Priſmes*, and conſequently the Refractions alike in both, it argues, that they were perform'd according to ſome *Conſtant Law* without any irregularity.

9. That there are more than two Original Colors.

To determine the *ſecond* Quære, the *Animadverſor* referrs to an Experiment made with two *Wedge-like boxes*, recited in the *Micrography* of the Ingenious Mr. *Hook* Obſerv. 10. pag. 73. the deſign of which was to produce *all* Colours out of a mixture of *two*. But there is, I conceive, a double defect in this inſtance. For, it appears not, that by this Experiment all colours can be produced out of two; and, if they could, yet the Inference would not follow.

That *all* Colours cannot by that Experiment be produced out of two, will appear by conſidering, that the Tincture of *Aloes*, which afforded one of thoſe Colours, was not all over of one uniform colour, but appear'd *yellow* near the edge of the Box, and *red* at other places where it was thicker; affording all variety of colours from a *pale yellow* to a *deep red* or Scarlet, according to the various thickneſs of the liquor. And ſo the ſolution of *Copper*, which afforded the other colour, was of various *Blews* and *Indigo's*. So that inſtead of *two* colours, here is a great variety made uſe of for the production of all others. Thus, *for inſtance*, to produce all ſorts of *Greens*, the ſeveral degrees of *Yellow* and *pale Blew* muſt be mixed ; but to compound *Purples*, the *Scarlet* and *deep Blew* are to be the Ingredients.

Now, if the *Animadverſor* contend, that all the *Reds* and *Yellows* of the one Liquor, or *Blews* and *Indigo's* of the other, are only various degrees and dilutings of the ſame Colour, and not divers colours, that is a Begging of the Queſtion : And I ſhould as ſoon grant, that the two *Thirds* or *Sixths* in Muſick are but ſeveral degrees of the ſame ſound, and not divers ſounds. Certainly it is much better to believe our Senſes, informing us, that *Red* and *yellow* are divers colours, and to make it a Philoſophical *Quære*, Why the ſame Liquor doth, according to its various thickneſs, appear of thoſe divers colours, than to ſuppoſe them to be the ſame colour becauſe exhibited by the ſame liquor ? For, if that were a ſufficient reaſon, then *Blew* and *Yellow* muſt alſo be the ſame colour, ſince they are both exhibited by the ſame Tincture of *Nephritick Wood.* But that they are *divers* colours, you will more fully underſtand by the reaſon, which, in my Judgment, is this : The Tincture of *Aloes* is qualified to tranſmit *moſt eaſily* the rays indued with *red*, *moſt difficultly* the rays indued with *violet*, and with *intermediat degrees of facility* the rays indued with *intermediat* colours. So that where the liquor is very thin, it may ſuffice to intercept moſt of the *violet*, and yet tranſmit moſt of the other colours ; all which together muſt compound a middle Colour, that is, a *faint yellow*. And where it is ſo much thicker as alſo to intercept moſt of the *Blew* and *Green*, the remaining *Green*, *Yellow*, and *Red*, it muſt compound an *Orenge*. And where the thickneſs is ſo great, that ſcarce any rays can paſs through it beſides thoſe indued with *Red*, muſt appear of that colour, and that ſo much the deeper and obſcurer, by how the liquor is thicker. And the ſame may be underſtood of the various degrees of *Blew*, exhibited by the Solution of *Copper*, by reaſon of its diſpoſition to intercept *Red* moſt eaſily, and tranſmit a *deep Blew* or *Indigo*-Colour moſt freely.

But, ſuppoſing that *all* Colours might,according to this experiment,be produced out of *two* by mixture ; yet it follows not, that thoſe two are the only *Original* colours, and that for a double reaſon. *Firſt*, becauſe thoſe two are not themſelves Original colours, but compounded of others ; there being no liquor nor any other body in nature,whoſe colour in Day-light is wholly un-compounded. And *then*, becauſe, though thoſe two were Original, and all others might be compounded of them, yet it follows not, that they cannot be otherwiſe produced. For I ſaid, that they had a double Origin, the ſame Colours to ſenſe being in ſome caſes compounded and in others un-compounded ; and ſufficiently declar'd in my *third* and *fourth* Propoſitions, and in the Concluſion, by what Properties the one might be known and diſtinguiſh't from the other. But, becauſe I ſuſpect by ſome Circumſtances, that the *Diſtinction* might not be rightly apprehended, I ſhall once more declare it, and further explain it by Examples.

That Colour is *Primary* or *Original*, which cannot by any Art be changed, and whoſe Rays are not *alike* refrangible : And that *Compounded*, which is changeable into other colours, and whoſe Rays are *not alike* refrangible. *For inſtance*, to know, whether the colour of any *Green* object be compounded or not, view it through a Prime, and if it appear *confuſed*, and the edges tinged with *Blew*, *Yellow*, or any variety of other colours, then is that *Green* compounded of ſuch colours as at its edges emerge out of it : But if it appear *diſtinct*, and well defin'd, and entirely Green to the very edges, without any other colours emerging, it is of an Original and un-compounded Green. In like manner, if a refracted beam of light, being caſt on a white wall, exhibit a *Green* colour, to know whether that be compounded, refract the beam with an interpoſed Priſme ; and if you find any Difformity in the refractions, and the *Green* be transform'd into *Blew*, *Yellow*,or any variety, of other colours, you may conclude, that it was compounded of thoſe which emerge : But if the Refractions be uniform, and the *Green* perſiſt without any change of colour, then is it Original and un compounded. Andthe reaſon why I call it ſo, is, becauſe a *Green* indued with ſuch properties cannot be produced by any mixing of other colours.

Now, if two *Green* Objects may to the naked eye appear of the ſame colour, and yet one of them through a priſme ſeem *confuſed* and variegated with other colours at the edges, and the other *diſtinct* and entirely Green; or, if there may be two Beams of Light, which falling on a white wall do to the naked eye exhibit the ſame *Green* colour, and yet one of them, when tranſmitted through a Priſme, be uniformly and *regularly* refracted, and retain its colour unchanged, and the other be *irregularly* refracted and, to divaricate into a multitude of other colours; I ſuppoſe, theſe two *greens* will in both caſes be granted of a different Origin and conſtitution. And if by mixing colours, a *green* cannot be compounded with the properties of the *Vnchangeable* Green, I think, I may call *that* an *Vn-compounded* colour, eſpecially ſince its rays are alike refrangible, and uniform in all reſpects.

The ſame rule is to be obſerv'd in examining, whether *Red*, *Orenge*, *Yellow*, B*lew*, or any other colour be compounded or not. And, by the way, ſince all *White* objects through the Priſme appear confus'd and terminated with colours, *Whiteneſs* muſt, according to this diſtinction, be ever compounded, and that the moſt of all colours, becauſe it is the moſt confus'd and changed by Refractions.

From hence I may take occaſion to communicate a way for the improvement of *Microſcopes* by Refraction. The way is, by illuminating the Object in a darkned room with Light of any convenient colour not too much compounded: for by that means the Microſcope will with diſtinctneſs bear a deeper Charge and larger Aperture, eſpecially if its conſtruction be ſuch, as I may hereafter deſcribe; for, the advantage in Ordinary Microſcopes will not be ſo ſenſible.

10. *That Whiteneſs is a mixture of all Colours.*

There remains now the *third* Quære to be conſider'd, which is, Whether *Whiteneſs* be an Uniform Colour, or a diſſimilar Mixture of all colours? The Experiment which I brought to decide it, the *Animadverſor* thinks may be otherwiſe explain'd, and ſo concludes nothing. But he might eaſily have ſatisfied himſelf by trying, what would be the reſult of a Mixture of all colours. And that very Experiment might have ſatisfied him, if he had pleaſed to examine it by the various circumſtances. One circumſtance I there declared, of which I ſee no notice taken; and it is, That if any colour at the *Lens* be intercepted, the *Whiteneſs* will be changed into the other colours: If all the colours but *red* be intercepted, that Red alone in the concourſe or croſſing of the Rays will not conſtitute Whiteneſs, but continues as much Red as before; and ſo of the other colours. So that the buſineſs is not only to ſhew, how rays, which before the concourſe exhibit colours, do in the concourſe exhibit *White*; but to ſhew, How in the ſame place, where the ſeveral ſorts of rays apart exhibit ſeveral colours, a Confuſion of all together make White. For inſtance, if red alone be firſt tranſmitted to the paper at the place of concourſe, and then the other colours be let fall on that Red, the *Queſtion* will be, Whether they convert it into White, by mixing with it only, as Blew falling on Yellow light is ſuppos'd to compound Green; or, Whether there be ſome further change wrought in the colours by their mutual acting on one another, untill, like contrary *Peripatetic* qualities, they become aſſimilated. And he that ſhall explicate this laſt Caſe *mechanically*, muſt conquer a double impoſſibility. He muſt *firſt* ſhew, that many unlike motions in a Fluid can by claſhing ſo act on one another, and change each other, as to become one Uniform motion; and *then*, that an Uniform motion can of it ſelf, without any new unequal impreſſions, depart into a great variety of motions regularly un-equal. And after this he muſt further tell me, Why all Objects appear not of the ſame colour, that is, why their colours in the Air, where the rays that convey them every way are confuſedly mixt, do not aſſimilate one another and become Uniform before they arrive at the Spectators eye?

But if there be yet any doubting, 'tis better to put the Event on further Circumſtances of the *Experiment*, than to acquieſce in the poſſibility of any *Hypothetical* Explication. As, for inſtance, by trying, What will be the apparition of theſe colours in a very quick Conſecution of one another. And this may be eaſily perform'd by the rapid gyration of a Wheel with many Spoaks or coggs in its perimeter, whoſe Interſtices and thickneſſes may be equal and of ſuch a largeneſs, that, if the Wheel be interpoſed between the Priſme and the white concourſe of the colours, one half of the Colours may be intercepted by a ſpoake or cogg, and the other half paſs through an interſtice. The Wheel being in this poſture, you may firſt turn it ſlowly about, to ſee all the colours fall ſucceſſively on the ſame place of the paper, held at their aforeſaid concourſe; and if you then accelerate its gyration, until the Conſecution of thoſe colours be ſo quick, that you cannot diſtinguiſh them ſeverally, the reſulting colour will be a Whiteneſs perfectly like that, which an un-refracted beam of Light exhibits, when in like manner ſucceſſively interrupted by the ſpoaks or coggs of that circulating Wheel. And that this *Whiteneſs* is produced by a ſucceſſive Intermixture of the Colours, without their being aſſimilated, or reduc'd to any Uniformity, is certainly beyond all doubt, unleſs things that exiſt not at the ſame time may notwithſtanding act on one another.

There are yet other Circumſtances, by which the Truth might have been decided; as by viewing the White concourſe of the Colours through another Priſme plac'd cloſe to the eye, by whoſe Refraction that whiteneſs may appear again tranſform'd into Colours: And then, to examine their Origin, if an Aſſiſtant intercept any of the colours at the *Lens* before their arrival at the Whiteneſs, the ſame colours will vaniſh from amongſt thoſe, into which that Whiteneſs is converted by the *ſecond* Priſme. Now, if the rays which diſappear be the ſame with thoſe that are intercepted, then it muſt be acknowledged, that the *ſecond* Priſme makes no new colours in any rays, which were not in them *before* their concourſe at the paper. Which is a plain indication, that the rays of ſeveral colours remain diſtinct from one another in the Whiteneſs, and that from their *previous* diſpoſitions are deriv'd the Colours of the *ſecond* Priſme. And, by the way, what is ſaid of their Colors may be applied to their Refrangibility.

The aforeſaid *Wheel* may be alſo here made uſe of; and, if its gyration be neither too quick nor two ſlow, the ſucceſsion of the colours may be diſcern'd through the Priſme, whilſt to the naked eye of a Byſtander they exhibit whiteneſs.

There is ſomething ſtill remaining to be ſaid of this Experiment. But this, I conceive, is enough to enforce it, and ſo to decide the controverſy. How-ever, I ſhall now proceed to ſhew ſome other ways of producing *Whiteneſs by mixtures*, ſince I perſwade my ſelf, that this Aſſertion above the reſt appears Paradoxical, and is with moſt difficulty admitted. And becauſe the *Animadverſor* deſires an inſtance of it in Bodies of divers colours, I ſhall begin with that. But in order thereto it muſt be conſider'd, that ſuch colour'd Bodies reflect but ſome part of the Light incident on them ; as is evident by the 13 *Propoſition* : And therefore the Light reflected from an Aggregat of them will be much weakned by the loſs of many rays. Whence a perfect and *intenſe* Whiteneſs is not to be expected, but rather a Colour between thoſe of Light and Shadow, or ſuch a Gray or Dirty colour as may be made by mixing White and Black together.

And that ſuch a Colour will reſult, may be collected from the colour of *Duſt* found in every corner of an houſe, which hath been obſerv'd to conſiſt of many colour'd particles. There may be alſo produced the like Dirty colour by mixing ſeveral *Painters colours* together. And the ſame may be effected by Painting a *Top* (ſuch as Boys play with) of divers colours. For, when it is made to circulate by whipping it, it will appear of ſuch a dirty colour.

Now, the Compounding of theſe colours is proper to my purpoſe, becauſe they differ not from Whiteneſs in the *Species* of colour, but only in *degree* of Luminouſneſs : which (did not the *Animadverſor* concede it) I might thus evince. A beam of the Suns Light being tranſmitted into a darkned room, if you illuminate a ſheet of White Paper by that Light, reflected from a body of any colour, the paper will always appear of the colour of that body, by whoſe reflected light it is illuminated. If it be a red body, the paper will be red ; if a green body, it will be green ; and ſo of the other colours. The reaſon is, that the fibers or threds, of which the paper conſiſts, are all tranſparent and ſpecular ; and ſuch ſubſtances are known to reflect colours without changing them. To know therefore, to what *Species* of colour a *Grey* belongs, place any Gray body (ſuppoſe a Mixture of *Painters colours*,) in the ſaid Light, and the paper, being illuminated by its reflexion, ſhall appear White. And the ſame thing will happen, if it be illuminated by reflexion from a *black* ſubſtance.

Theſe therefore are all of one *Species* ; but yet they ſeem diſtinguiſht not only by *degrees* of Luminouſneſs, but alſo by ſome other Inequalities, whereby they become more harſh or pleaſant. And the diſtinction ſeems to be, that *Greys* and perhaps *Blacks* are made by an uneven defect of Light, conſiſting as it were of many little veins or ſtreams, which differ either in Luminouſneſs or in the Unequal diſtribution of diverſly colour'd rays ; ſuch as ought to be caus'd by Reflexion from a Mixture of white and black, or of diverſly colour'd corpuſcles. But when ſuch imperfectly mixt Light is by a *ſecond* Reflexion from the paper more evenly and uniformly blended, it becomes more pleaſant, and exhibits a *faint* or ſhadow'd Whiteneſs. And that ſuch little irregularities as theſe may cauſe theſe differences, is not improbable, if we conſider, how much variety may be cauſed in *Sounds* of the ſame tone by irregular and uneven jarrings. And beſides, theſe differences are ſo little, that I have ſometimes doubted, whether they be any at all, when I have conſider'd that a Black and White Body being plac'd together, the one in a ſtrong light, and the other in a very faint light, ſo proportion'd that they might appear equally luminous ; it has been difficult to diſtinguiſh them, when view'd at diſtance, unleſs when the Black ſeem'd more blewiſh ; and the White body in a light ſtill fainter, hath, in compariſon of the Black body, it ſelf appear'd Black.

This leads me to another way of *Compounding Whiteneſs* ; which is, That, if four or five Bodies of the more eminent colours, or a Paper painted all over, in ſeveral parts of it, with thoſe ſeveral colours in a due proportion, be placed in the ſaid Beam of Light ; the Light, reflected from thoſe Colours to another White paper, held at a convenient diſtance, ſhall make that paper appear White. If it be held too near the Colours, its parts will ſeem of thoſe colours that are neareſt them ; but by removing it further, that all its parts may be equally illuminated by all the colours, they will be more and more diluted, until they become perfectly White. And you may further obſerve, that if any of the colours be intercepted, the Paper will no longer appear White, but of the other colours which are not intercepted. Now, that this *Whiteneſs* is a Mixture of the ſeverally colour'd rays, falling confuſedly on the paper, I ſee no reaſon to doubt of ; becauſe, if the Light became Uniform and Similar before it fell confuſedly on the paper, it muſt much more be Uniform, when at a greater diſtance it falls on the Spectators eye, and ſo the rays, which come from ſeveral colours, would in no qualities differ from one another, but all of them exhibit the ſame colour to the Spectator, contrary to what he ſees.

Not much unlike this Inſtance it is, That, if a poliſht piece of Metal be ſo placed, that the colours appear in it as in a Looking-glaſs, and then the Metal be made rough, that by a confus'd reflexion thoſe apparent colours may be blended together, they ſhall diſappear, and by their mixture cauſe the Metall to look White.

But further to enforce this *Experiment*; if, inſtead of the Paper, any White *Froth*, conſiſting of ſmall bubles, be illuminated by reflexion from the aforeſaid Colours, it ſhall to the naked eye ſeem White, and yet through a good Microſcope the ſeveral Colours will appear diſtinct on the bubles, as if ſeen by reflexion from ſo many ſpherical ſurfaces. With my naked eye, being very near, I have alſo diſcern'd the ſeveral colours on each buble; and yet at a greater diſtance, where I could not diſtinguiſh them apart, the Froth hath appear'd entirely White. And at the ſame diſtance, when I look'd intently, I have ſeen the colours diſtinctly on each buble; and yet, by ſtraining my eyes as if I would look at ſomething far off beyond them, thereby to render the Viſion confus'd, the Froth has appear'd without any other colour than Whiteneſs. And what is here ſaid of Froths, may eaſily be underſtood of the Paper or Metal in the foregoing Experiments. For, their parts are ſpecular bodies, like theſe Bubles: And perhaps with an excellent Microſcope the Colours may be alſo ſeen intermixedly reflected from them.

In proportioning the ſeverally Colour'd bodies to produce theſe effects, there may be ſome niceneſs; and it will be more convenient, to make uſe of the colours of the Priſme, caſt on a Wall, by whoſe reflexion the Paper, Metal, Froth, and other White ſubſtances may be illuminated. And I uſually made my Tryals this way, becauſe I could better exclude any ſcattering Light from mixing with the colours to dilate them.

To this way of Compounding Whiteneſs may be referr'd that other, by Mixing light after it hath been trajected through tranſparently colour'd ſubſtances. *For inſtance*, if no Light be admitted into a room but only through Colour'd glaſs, whoſe ſeveral parts are of ſeveral colours in a pretty equal proportion; all White things in the room ſhall appear White, if they be not held too near the Glaſs. And yet this light, with which they are illuminated, cannot poſſibly be uniform, becauſe, if the Rays, which at their entrance are of divers colours, do in their progreſs through the room ſuffer any alteration to be reduced to an Uniformity; the Glaſs would not in the remoteſt parts of the room appear of the very ſame colour, which it doth when the Spectators eye is very near it: Nor would the rays, when tranſmitted into another dark room through a little hole in an oppoſite door or partition-wall, project on a Paper the *Species* or repreſentation of the glaſs in its proper colours.

And, by the by, this ſeems a very fit and cogent Inſtance of ſome other parts of my *Theory*, and particularly of the 13 *Propoſition*. For, in this room all natural Bodies whatever appear in their proper colours. And all the *Phænomena* of colours in nature, made either by Refraction or without it, are here the ſame as in the Open Air. Now, the Light in this room being ſuch a Diſſimilar mixture, as

I have deſcrib'd in my *Theory*, the Cauſes of all theſe *Phænomena* muſt be the ſame that I have there aſſign'd. And I ſee no reaſon to ſuſpect, that the ſame *Phænomena* ſhould have other cauſes in the Open Air.

The ſucceſs of this Experiment may be eaſily conjectur'd by the appearances of things in a Church or Chappel, whoſe windores are of colour'd glaſs; or in the Open Air, when it is illuſtrated with Clouds of various colours.

There are yet other ways, by which I have produced *Whiteneſs*; as *by* caſting ſeveral Colours from two or more Priſmes upon the ſame place; *by* Refracting a Beam of Light with two or three Priſmes ſucceſſively, to make the diverging colours converge again; *by* Reflecting one colour to another; and *by* looking through a Priſme on an Object of many colours; and, (which is equivalent to the above mention'd way of mixing colours by concave *Wedges* fill'd with colour'd liquors,) I have obſerv'd the ſhadows of a painted Glaſs-window to become White, where thoſe of many colours have at a great diſtance interfered. But yet, for further ſatisfaction, the *Animadverſor* may try, if he pleaſe, the effects of four or five of ſuch *Wedges* filled with liquors of as many ſeveral colours.

Beſides all theſe, the Colours of *Water-bubbles* and other thin pellucid ſubſtances afford ſeveral inſtances of Whiteneſs produced by their mixture; with *one* of which I ſhall conclude this particular. Let ſome Water, in which a convenient quantity of Soap or waſh-ball is diſſolv'd, be agitated into Froth, and, after that froth has ſtood a while without further agitation, till you ſee the bubbles, of which it conſiſts, begin to break, there will appear a great variety of colours all over the top of every bubble, if you view them near at hand; but, if you view them at ſo great a diſtance that you cannot diſtinguiſh the colours one from another, the Froth will appear perfectly White.

II. *That the* Experimentum crucis *is ſuch.*

Thus much concerning the deſign and ſubſtance of the *Animadverſor's* Conſiderations. There are yet ſome particulars to be taken notice of, before I conclude; as the denyal of the *Experimentum Crucis*. On *this* I choſe to lay the whole ſtreſs of my diſcourſe; which therefore was the principal thing to have been objected againſt. But I cannot be convinced of its inſufficiency by a bare denyal without aſſigning a Reaſon for it. I am apt to believe, it has been miſunderſtood; for otherwiſe it would have prevented the diſcourſes about Rarifying and Splitting of rays; becauſe the deſign of it is, to ſhew, that Rays of divers colours, conſider'd a part, do at *Equal* Incidences ſuffer *Unequal* Refractions, without being ſplit, rarified, or any ways dilated.

12. Some particulars recommended to further conſideration.

In the Conſiderations of my firſt and ſecond Propoſitions, the *Animadverſor* hath rendred my Doctrine of *Un-equal Refrangibility* very imperfect and maimed, by explicating it wholly by the Splitting of rays; whereas I chiefly intended it in thoſe Refractions that are perform'd without that ſuppos'd Irregularity; ſuch as the *Experimentum Crucis* might have inform'd him of. And, in general I find, that, whilſt he hath endeavour'd to explicate my Propoſitions *Hypothetically*, the more material ſuggeſtions, by which I deſign'd to recommend them, have eſcap'd his conſideration; ſuch as are, The Unchangeableneſs of the degree of Refrangibility peculiar to any ſort of rays; the ſtrict Analogy between the degrees of Refrangibility and Colours; the Diſtinction between compounded and un-compounded colours; the Unchangeableneſs of un-compounded colours; and the Aſſertion, that if any one of the Priſmatique colours be wholly intercepted, that colour cannot be new produced out of the remaining Light by any further Refraction or Reflexion whatſoever. And of what ſtrength and efficacy theſe Particulars are for enforcing the *Theory*, I deſire therefore may be now conſider'd.

An Accompt of two Books.

I. *Ottonis de Guericke EXPERIMENTA NOVA MAGDEBURGICA, de VACUO SPATIO*, &c. Amſtelodami A. 1672. in fol.

After that the famous Author of this Book hath made a Narrative of the chief *Hypotheſes* and Opinions of both Antient and Recent Aſtronomers concerning the Syſteme of the world, and repreſented the great difficulties in the *Ptolemaique* and *Tychonique*, and repeated the Anſwers to the Objections againſt the *Copernican*; he at large gives us his own Thoughts of the Frame and Conſtitution of the *World*; By which *World* he underſtands in this Treatiſe the Complex of the Planets, diſpoſed and order'd much after the *Copernican* way, the *Sun* being ſeated in the midſt, having his Spots about him, and moving and influencing all the reſt of the *Planets* according to their ſeveral diſtances from him; *Saturn* making the utmoſt of all the Planets, and the End of this his World being there, where the diffuſive power and vertue of the Sun, the King and Governor of them all, terminates; which bounds he conjectures to extend themſelves, beyond *Saturn*, to thoſe Fixt Stars that are of the nearer rank to *Saturns* Orbe.

Concerning the Bodies lodged in theſe Planets, he thinks it conſonant to the Power and Wiſdom of the Great Creator, that there ſhould be ſuch a variety of them, as to ſtock each of the ſaid Planets,

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